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ANNUAL PROGRESS REPORT

1 SEPTEMBER 1967 to 30 JUNE 1968

GRANT DA - DA - 17 - 68 - G9249

OCULAR EFFECTS OF MICROWAVE RADIATION

Milton M. Zaret, M.D.

Principal Investigator

Supported by

U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND

THE ZARET FOUNDATION, INC.
1230 POST ROAD
SCARSDALE, NEW YORK

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DATE: 18 Nov 68

MEMORANDUM THRU: CHIEF, RESEARCH DIVISION

FOR: CHIEF, PURCHASING AND CONTRACTING OFFICE, USAMRDC

SUBJECT: ~~Contract~~/Grant No. 9249 (DA-17-68-G 9249)

Institution ZARET FOUNDATION, INC.

Principal Investigator MILTON M. ZARET M.D.

1. FINAL REPORT: The report checked below is accepted as the Final Scientific/Technical Report under the above referenced contract/grant and is considered satisfactory.

for the period 1 SEP 67 - 30 JUN 68

✓ Final Scientific Report, dated OTHERWISE UNDATED

_____ Progress Report No. _____, dated _____

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2. SUMMARY OF RESULTS (Applicable to grants only).

The results of this study indicate that lenticular sensitivity to microwaves is greater with high frequency irradiation; less energy was required to produce cataracts at 5.2 GHz than at 4.2 GHz. Comparison with prior work showed an overall decrease in the threshold energy as the frequency is increased.

[signature] Col (MC)
Project Officer

CTEG Fl. 103, 1 Feb 67

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ABSTRACT

This report deals with an experimental investigation of the ocular hazard associated with exposure to microwaves. The studies were concerned primarily with determining energy thresholds for the production of lenticular opacities (cataracts) in rabbit eyes using both CW and pulsed power at selected frequencies in the range of 4.2 to 5.5 GHz.

Preliminary to the conduct of these experiments, it was necessary to derive a technique whereby the microwave power from a relatively large cross-sectional area of waveguide could be delivered to the small ocular aperture of the rabbit eye. This was accomplished by a modification of the "closed waveguide system" developed by Carpenter, in which the eye of an anestetized animal terminates a length of waveguide. It was then possible to utilize conventional microwave calibration methods for determining power levels at the eye.

Irreversible lenticular damage usually developed within four days after exposure, although in some cases a longer latent period ensued between exposure and detectable injury. Accordingly, a four week post-irradiation period was chosen as the time interval within which lenticular opacification was included as a positive finding.

To determine cataractogenic threshold for a given microwave frequency, rabbits were exposed for varying durations to a range of power levels. The criterion for threshold was that quantity of energy (i.e., power x exposure duration) which gave rise to cataract formation in 50% of the exposed eyes. Threshold curves for both CW and pulsed (.001 duty cycle) microwaves were essentially similar indicating that average power level rather than peak power was the significant factor for inducing cataract. Furthermore, results obtained at 4.2, 5.2, 5.4 and 5.5 GHz suggest that the lens is maximally sensitive to high-frequency microwaves, and there is a monotonic rise in threshold as the frequency is reduced from 5.5 to 4.2 GHz. On the basis of these results, it is essential to extend the range of frequencies studied to 6.0 GHz in order that the form of the cataractogenic action spectrum be more precisely defined.

INTRODUCTION

Considerable interest in the ocular hazards of microwave exposure has developed in recent years owing to the extensive use of powerful microwave transmitters for military, industrial, radio-navigation and communication purposes. As the power levels of microwave systems are enhanced, it becomes increasingly important to establish realistic, safe limits for personnel exposure. That these limits are frequently exceeded is attested to by the fact that there are now 96 documented cases of human lens injury resulting from microwave irradiation, as well as several other suspected instances of serious injury, e.g. testicular tumor, infertility and non-specific cardiovascular and thyroid damage. Experimentally, these and other abiotic effects, e.g., impairment of neural, pulmonary, and hematologic function, are readily demonstrated.

Although the mechanism for microwave damage is presumed to be thermal in origin, the obstacles to locating the site of energy absorption and measuring temperature gradients _in vivo_, makes it desirable to employ tissue reaction as the response metric for determining sensitivity. Furthermore, since the absorption of radiant energy by biological tissues is invariably frequency-dependent, a complete description of tissue sensitivity involves the determination of an action spectrum. The latter represents the energy required to produce a constant (or criterion) response, e.g., threshold, as a function of the frequency of the incident radiation.

Sufficient data are not currently available, however, to specify safe exposure levels for the range of frequencies comprising the microwave spectrum. The present work, involving irradiation at 4.2, 5.2, 5.4 and 5.5 GHz, in both CW and pulsed modes, represents a series of measurements to be utilized in the derivation of a cataractogenic action spectrum. These data enable us to define more precisely the relative sensitivity of the lens to microwave frequencies.

METHODS

Apparatus.

The technique employed for ocular irradiation was the "closed waveguide" system developed by Carpenter (1962). This consisted of using one eye of an anesthetized animal as the RF termination for a length of waveguide, and enabled the use of standard microwave instrumentation for precise measurements on the power entering the animal's eye.

Initially, a metal plate with a centered 0.5 inch aperture was placed directly at the end of the waveguide, and eye was centered upon the aperture. However, very large reflections were observed (the standing wave ratio was about 30) necessitating the introduction of an E-H tuner between the source and the terminal aperture for purposes of matching. But certain difficulties were encountered with this method. An E-H tuner without losses of its own is capable theoretically of matching the iris to the waveguide so that all of the incident power is delivered to the eye. In this ideal case, it is necessary merely to measure the incident power in the waveguide to determine the power entering the eye. Unfortunately, the tuner exhibits substantial losses when required to match very large standing wave ratios, and it was necessary to estimate the power loss occurring during transmission. This was accomplished by measuring the power transmitted through the iris into a matched detector, on the assumption that the insertion loss of the tuner-iris combination did not change materially when the E-H tuner was reset to obtain a matched condition with the rabbit's eye. In this way, we estimated the loss to be about 3.0 - 3.5 db.

During an experimental session, slight movements of the rabbit's eye made it necessary to continuously retune the device, so that a fixed tuner setting could not be maintained; i.e., the transmission losses were variable. Thus, there existed considerable uncertainty as regards power level during a single irradiation, as well as between exposures. In view of these difficulties, it appeared that a less abrupt method of terminating the waveguide was required.

Modification of the Transition Mode.

In order to achieve a more gradual transition from the waveguide to the animal's eye, i.e., one having lower reflections, a special adaptor was designed (cf. Rosenthal *et al.*, 1967). It consists of two sections, the first of which is a transition from C-band waveguide (RG-49/U or WR-187, with 1.872" x 0.872" inner dimensions) to ridged guide; the second is a length of circular waveguide. Both portions use Stycast inserts of relative dielectric constant 12. The function of the dielectric taper and of the ridged guide is to concentrate the energy normally distributed over a large cross-section in the rectangular waveguide, into a relatively small cross-section of approximately one square centimeter. The circular waveguide provides a good mechanical link with the animal's eye, since it contains a spherical depression to accommodate the cornea, and protrudes beyond the adaptor and the bony orbit within which the rabbit's eye is recessed.

Two important properties of the transition are its effectiveness in matching the eye to the waveguide without the need of a tuner, and the low power loss during transmission. The transmission efficiency was determined by various methods (calorimetric, standing-wave ratios) and indicated an average power loss of only 0.28 db for the range of frequencies used in this study (Trimble, 1967; Birenbaum, et al, in press).

Procedure.

Rabbits were anesthetized by intramuscular injection of sparine or promazine HCl (20mg/kg) followed about 15 minutes later by intraperitoneal sodium pentobarbital (35 mg/kg). Prior to exposure, both eyes were examined ophthalmoscopically. The left eye was then taped open and a few drops of wetting agent was instilled to prevent corneal dehydration; in all cases, the right eye was spared to serve as a control. The cornea of the test eye was placed in contact with the transition and the slide screw tuner adjusted for unity standing-wave ratio. After selecting the microwave frequency, the power level was adjusted to the desired dosage and continuously monitored by a thermistor and power meter attached to the output arm of a directional coupler. Calibration was performed before the start of each experiment and the exposure duration carefully timed.

After irradiation, the rabbit's eyes were examined for immediate effects. Subsequently, the animals were examined on the fourth day following exposure, and at weekly intervals thereafter. Only those instances of microwave damage occurring within a post-irradiation period of one month are included as positive reactions in the analysis of results.

RESULTS

The greater part of the year's work was done with pulsed (5 µsec, 200 pps) microwaves at 5.2 GHz although a number of exposures were conducted at 4.2 GHz. The results of fifty-eight experiments at 5.2 GHz with power levels ranging from 702 to 1134 mw are summarized in Table 1 and shown graphically in Fig. 1. Exposure to 702 mw for durations up to 90 minutes produced no lenticular opacification. At 810 mw, however, the exposure duration required to produce cataracts with a 50 per cent probability was between 30 and 40minutes. The cataractogenic threshold decreased to about 20 minutes at 918 mw, was 15 minutes at 1026 mw, and was between 7 and 10 minutes at 1134 mw.

The effects of CW power were also studied in a series of twenty-three exposures at 5.2 GHz. Although the source was unstable in the CW mode, the results indicate that thresholds were not significantly different from those obtained with pulsed radiation of equivalent frequency and average power.

Dependence of the cataractogenic threshold on microwave frequency is suggested by a comparison of the foregoing data with the results of 22 exposures at 4.2 GHz (cf. Table 2 and Fig.1). All experiments were conducted at 1026 mw, using pulsed power (5 µsec, 200 pps). For these conditions, the criterion for threshold was reached in 15 to 20 minutes as compared with 15 minutes for 5.2 GHz of the same power.

Table 1

Results of 5.2 GHz Pulsed Exposures

200 pps, 5µsec pulses

Average Power Level (milliwatts)	Exposure Duration (minutes)	Number of Exposures	Number of Cataracts	Ratio of Cataracts to Exposures
702	50	1	0	0
	60	2	0	0
	70	1	0	0
	90	1	0	0
810	30	3	1	.33
	40	3	3	1.00
918	15	4	1	.25
	20	3	2	.67
	30	3	3	1.00
	40	2	2	1.00
1026	10	7	0	0
	15	12	6	.50
	20	5	4	.80
1134	5	1	0	0
	7	4	1	.25
	10	6	4	.75

Table 2

Results of 4.2 GHz Pulsed Exposures

200 pps, 5µsec pulses

Average Power Level (milliwatts)	Exposure Duration (minutes)	Number of Exposures	Number of Cataracts	Ratio of Cataracts to Exposures
1026	15	8	1	.13
	20	9	8	.89
	30	5	4	.80

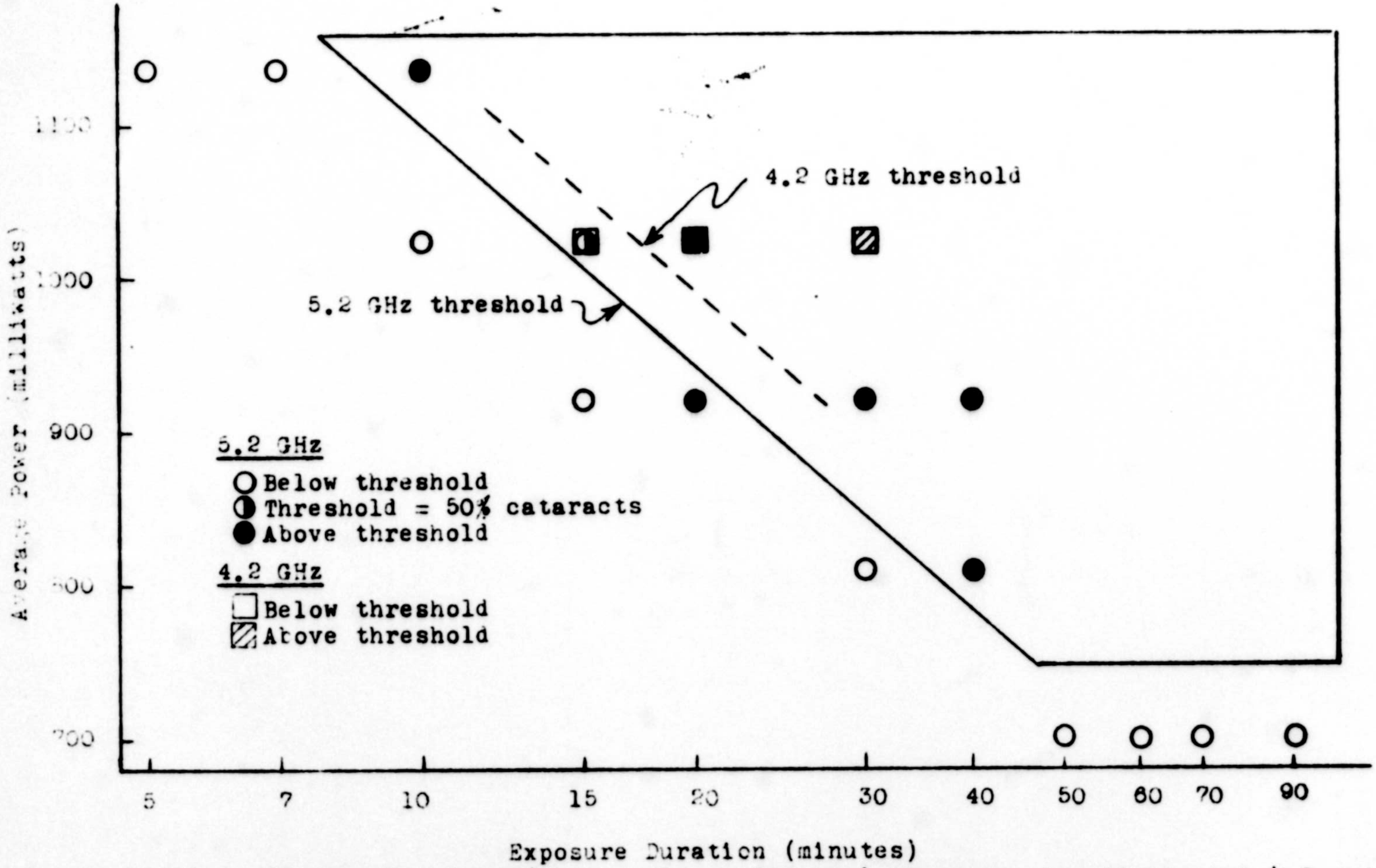

Fig. [illegible] The lenticular effects of pulsed (5μsec pulses, 200 pps) microwave irradiation at 4.2 and 5.2 GHz. Filled symbols indicate that 50 per cent cataractogenic threshold was exceeded; open symbols signify that less than half the exposures at the indicated power and duration produced cataracts. Data points summarize the results for 5.2 GHz (circles) over the range of 702 to 1134mw, and 4.2 GHz (squares) at 1026 mw. Thus, the solid line labelled 5.2 GHz threshold encloses the region in which more than 50 per cent of the exposures resulted in cataract formation, whereas the broken line represents the cataractogenic threshold for 4.2 GHz on the assumption that at all power levels the function parallels that obtained at 5.2 GHz.

Discussion and Conclusion

The results of this study indicate that lenticular sensitivity to microwaves is greater with high frequency irradiation; less energy was required to produce cataracts at 5.2 GHz than at 4.2 GHz. Table 3 combines the present results for a power level of 1026 mw with those of previous years. The energy required to produce cataracts in 50% of the exposures is presented for 4.2, 5.2, 5.4, and 5.5 GHz. Over-all, the threshold energy decreased as the frequency increased. To determine an action spectrum, however, a large range of frequencies at e.g. two selected power levels, should be intensively investigated during the same experimental period.

Lenticular opacification is only one of several forms of biological damage that are caused by microwaves. It is, nevertheless, the best documented and most objectively defined sign of microwave injury and one which is of major concern as regards personnel safety. Thus, a systematic examination of the factors which contribute to cataractogenesis can effectively eliminate the use of rather arbitrary and unrealistic safety practices. These, in turn, have led to unwarranted economic and operational burdens on the administration of military establishments. Since the evidence presented here indicates that the cataractogenic threshold is frequency dependent, it is essential to extend the range of frequencies investigated to provide a basis for specifying safe exposure levels across the microwave spectrum.

Table 3

Thresholds at 1026 mw

Frequency (GHz)	Wavelength (cm)	Threshold Duration (min)	Threshold Energy (Joules)
5.5	5.5	2.6	160
5.4	5.6	2.8	180
5.2	5.8	15.0	920
4.2	7.1	17.5	1080

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